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Development of Accelerometer Using Mach-Zehnder Interferometer Type Optical Waveguide

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1. Introduction

Currently, almost of micro-machined accelerometers which detects an acceleration electro-statically, electro-magnetically or piezo-resistively [1]-[3]. However, sensitivity of these sensors tends to degrease with those downsizing. Optical interference has a potential to solve the above mentioned problem. J. Zhou et al. reported an accelerometer using an optical Fabry-Perot interferometer [4]. However, fabrication cost of the senor becomes expensive because it needs accurate adjustment of optical axis at assembling process.

Therefore, we proposed a novel accelerometer which uses a MZI type optical waveguides as shown in Fig 1. In this sensor, a part of the waveguide is expanded by applied force, and then output of the MZI is changed by changing in its interference condition. This sensor has advantage that it does not needs optical axis adjustment because light is propagated only in the waveguide. In this paper, optical optimization by using simulation and evaluation results of an actually fabricated accelerometer are reported.

2. Measuring Principle

The proposed accelerometer shown in Fig. 1 consists of the MZI and cantilever; and there is a proof mass on the tip of cantilever. The MZI and the cantilever are fabricated by using device layer (also known as top layer) of the silicon on insulator (SOI) wafer which is crystal silicon. Here, one blanched waveguide in the MZI have floating beam structure (air-bridged type), and it is crosses with the cantilever in same plane. This cantilever is also fabricated using top layer of SOI wafer. When acceleration is applied to the mass, the cantilever and floating waveguide is deflected and expanded (Fig. 2). As a result, output of the MZI is changed by applied acceleration (Fig 3).

However, there is large optical loss at the cross point of a single-mode waveguide and cantilever. Moreover, this optical loss increases with width of the cantilever (Fig. 4). In order to decrease the optical loss, a part of the floating waveguide changes to MMI structure; and then the cantilever is crossed with the waveguide at MMI part (Fig. 5). When design of the MMI is optimized, there is rarefaction of a compression optical wave at the cross point with cantilever (Fig. 6). As a result, optical loss at the cross point drastically decrease, as long as the cantilever width is smaller than rarefied region of compression wave (Fig. 7).

3. Fabrication and Evaluation of Accelerometer

Proposed sensor is actually fabricated (Fig. 8). Here, BOX (SiO_2) layer of SOI wafer as sacrifice laver for the floating waveguide and cantilever is removed by a vapor of fluoric acid. Input and output light of the MZI are coupled with hemispherical lensed fiber (Fig. 9). Here, wavelength of input light is 1550 nm. As a measurement results, it is found that optical insertion loss of the MMI is approximately 0.1-0.2 dB and optical loss at the cross point of MMI and cantilever (50 µm width) is ~0.3 dB (Figs. 10 and 11). Since the sensor must be fixed on a sample stage of the measurement system, acceleration can not applies to the accelerometer. Therefore, the cantilever in the accelerometer is put directly by using tip of a needle in this study. As a result, it is recognized that the output of MZI is changed by applying force (Fig. 12).

4. Conclusion

A novel accelerometer which uses a MZI type optical waveguide made of crystal silicon is developed. In this sensor, one branched waveguide of the MZI have floating beam structure which is formed by removal of its underlying SiO_2 layer. As a result of evaluation, it is succeeded in changing in the output of MZI by applying a force to proof mass of the fabricated accelerometer.

Acknowledgements

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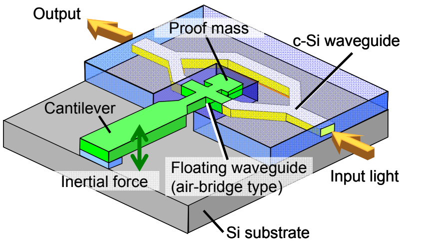

Fig. 1 Concept of inertial force sensor using Mach-Zehnder interferometer using optical waveguides made of crystal silicon.

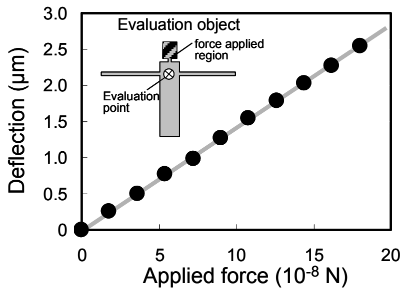

Fig. 2 Applied force versus deflection at cross point of floating waveguide and cantilever (simulated result using finite element method).

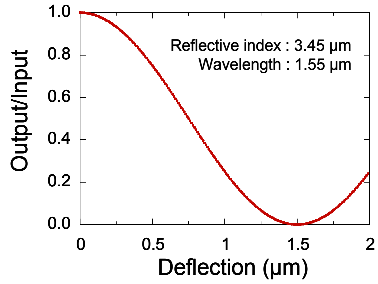

Fig. 3 Deflection versos output/input of MZI (calculated result).

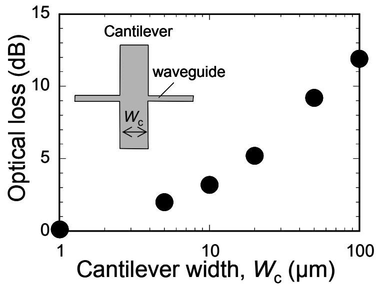

Fig. 4 Cantilever width versus optical loss at cross point when cantilever crosses with single-mode waveguide (simulated result).

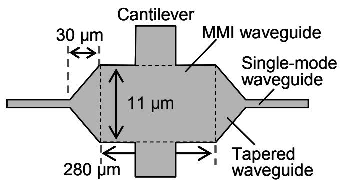

Fig. 5 Proposed intersectional form for decrease of optical loss. Here, single mode waveguide connects by tapered waveguide with MMI. Cantilever crosses with MMI at middle of MMI.

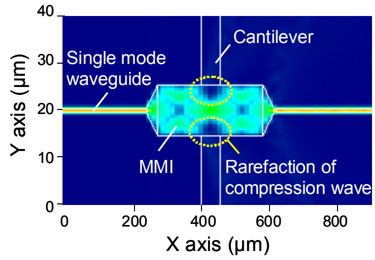

Fig. 6 Optical simulation around cross point of MMI waveguide and cantilever. There is compression wave in MMI waveguide, and there are two rarefactions around intersectional region of MMI and cantilever.

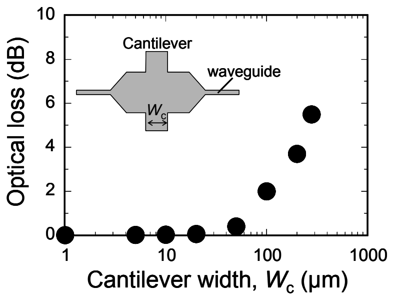

Fig. 7 Optical loss at MMI intersection versus width of cantilever (simulated result).

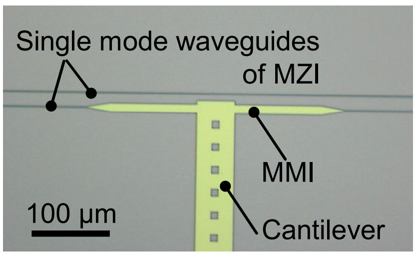

Fig. 8 Optical image of fabricated MZI type accelerometer (magnification around cross point of cantilever and MMI).

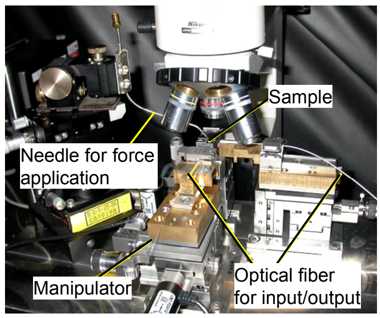

Fig. 9 Measurement system.

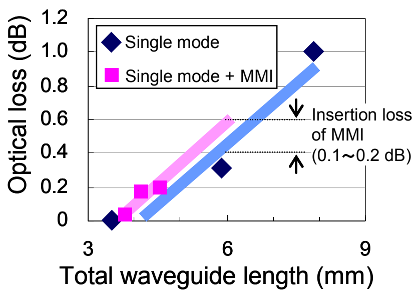

Fig. 10 Optical loss versus total length of waveguide including MMI (experimental result).

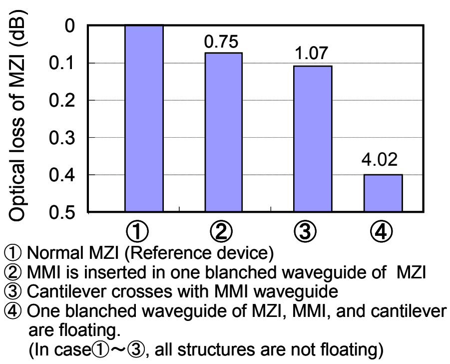

Fig. 11 Optical loss of fabricated special MZIs compared with output of normal MZI (experimental result).

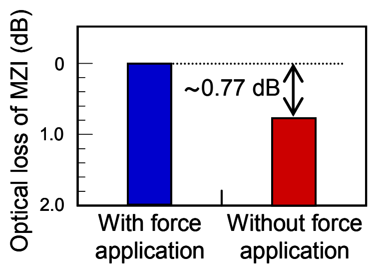

Fig. 12 Change in output of MZI by force application. In this measurement, the force is applied to middle of cantilever using needle (experimental result).